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Effectiveness of Using Backpack Electrofishing Gear for Collecting Sea Lamprey (*Petromyzon marinus*) Larvae in Great Lakes Tributaries

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***ABSTRACT**. The effects of water depth, larval density, stream conductance, temperature, lamprey length, and larval escapement were examined to determine the efficiency of sampling sea lamprey* (Petromyzon marinus) *larvae using direct current (DC) backpack electrofishing gear. A higher proportion of larvae of all sizes were collected per unit sampling effort when sample sites were shallower, contained fewer larvae, or were in streams of lower specific conductance ($P < 0.001$). Temperature did not affect the efficiency of sampling lamprey larvae in this study. The investigation of the effect of larval escapement on observed catch was inconclusive. Similar length distributions were found between lamprey larvae collected using electrofishing gear and those collected using either a suction dredge or collected during a lampricide treatment. These results have implications for the development of a sampling protocol that uses a single-pass electrofishing technique to estimate the overall abundance of sea lamprey larvae in a stream. This estimate is critical to determining the number of larvae with the potential to metamorphose as parasitic lamprey the following year, and consequently, the prioritization of streams for lampricide treatment.*

***INDEX WORDS:** Electrofishing, sampling efficiency, sea lamprey, logistic regression.*

INTRODUCTION

Sea lampreys (*Petromyzon marinus*) in the Great Lakes are currently controlled using an integrated approach, combining biological, physical, and chemical techniques. While biological (release of sterilized male sea lampreys) and physical (low-head barriers, mechanical traps) methods have the potential to reduce the reproductive success of sea lampreys, chemical control with the selective lampricide 3-trifluoromethyl-4-nitrophenol (TFM) remains the primary tool used to reduce sea lamprey populations. The rising cost of TFM coupled with public concerns about applying a synthetic chemi-

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cal to the environment has led the Great Lakes Fishery Commission (GLFC) to evaluate and prioritize which Great Lakes tributaries should receive TFM treatment in a given year. Treatment is recommended for those streams where the largest number of metamorphosed sea lampreys can be killed for each treatment dollar that is spent (Christie *et al.* 2003).

Central to this evaluation is the ability to quantify the larval sea lamprey population within each tributary. Up to 100 Great Lakes tributaries require quantitative assessment each year, necessitating the reliance on a systematic, rapid, single-pass technique using backpack electrofishing gear to sample lamprey larvae in wadable (depth < 0.8 m) streams. Slade *et al.* (2003) describe systematic techniques for sampling larval sea lampreys within a stream and estimating the number of larvae with the potential to metamorphose the following season. The techniques prescribe sampling sea lamprey larvae from measured and staked plots, 5 to 15 m^2 in area, in the wadable portions of streams, using direct current (DC) backpack electrofishing gear. The observed density of sea lamprey larvae collected during a single-pass episode of backpack electrofishing is corrected by a measure of gear efficiency to estimate the true density of larvae. The corrected densities are combined with measures of larval habitat, rates of growth, and probability of metamorphosis, to estimate a stream's capacity to produce parasitic sea lampreys the following year.

Sea lamprey larvae are sampled across a wide range of conditions throughout the Great Lakes basin, with each combination of conditions potentially contributing to variability in observed catch. Previous single-pass electrofishing sampling efficiency estimates for larval sea lampreys have ranged from 13% (D.W. Cuddy, Fisheries and Oceans Canada, Sault Ste. Marie, ON, unpublished data) to 70% (M. F. Fodale, Marquette Biological Station, Marquette, MI, unpublished data). Morkert (1987) reported a recapture of 21% of marked larvae of mixed species, and Daugherty and Dahl (1986) recovered between 50 and 85% (mean 69%) of a known number of sea lamprey larvae using backpack electrofishing gear under sampling conditions similar to those currently used to quantify larval sea lamprey abundance (Slade *et al.* 2003).

Variables such as conductivity (Pusey *et al.* 1998, Hill and Willis 1994), stream width (Kennedy and Strange 1981), fish size (Zalewski 1985, Bohlin and Sundstrom 1977), temperature (Regis *et al.* 1981), and operator experience (Hardin and Connor 1992) have been shown to affect electrofishing capture efficiency in teleosts. Further, laboratory studies have determined that the response of sea lamprey larvae to electrical stimuli can vary depending upon water conductance and temperature, substrate composition, and orientation of the electrical field (Weisser 1994, Hintz 1993). The presence and abundance of indigenous lamprey species will also affect the ability of the electrofishing operator to collect sea lamprey larvae. Each of these variables may contribute to the variability in capture efficiency for sea lamprey larvae that has been reported in previous studies.

Quantifying larval sea lamprey abundance relies on an accurate measure of electrofishing effectiveness to determine the true number and size structure of larval sea lampreys present within a stream. Two consecutive studies were conducted to evaluate the sampling effectiveness of backpack electrofishing gear. The initial study in the Pine, Rifle, and Traverse rivers in 1996 and 1997 was conducted to obtain a systematic estimate of average electrofishing efficiency in high and low conductivity Great Lakes tributaries. Sampling effectiveness in this preliminary study was estimated as the ratio of sea lamprey larvae captured by electrofishing to the initial abundance of sea lamprey larvae within the sample plot. This initial study examined the potential size selectivity of electrofishing techniques and the effects of larval escapement on observed catch, by comparing estimated larval sea lamprey densities in paired electrofishing (treatment) and control plots within each river. In 1998, the techniques of the initial study were extended to a second study, where the effects that stream- and site-specific conditions such as water conductivity and temperature, plot depth and larval lamprey density, and the size of larval sea lampreys have on sampling effectiveness using backpack electrofishing gear were measured and included in the analyses.

MATERIALS AND METHODS

Initial Study

Three streams, the Rifle, Pine, and Traverse rivers, were selected for the initial study conducted in 1996 and 1997 (Fig. 1). These streams were selected because they contained moderate to high densities (> 5 per m^2) of larval lamprey comprised of multiple year classes that would help ensure sample sizes large enough to detect differences in abundance and size structure between control and treatment plots (Table 1).

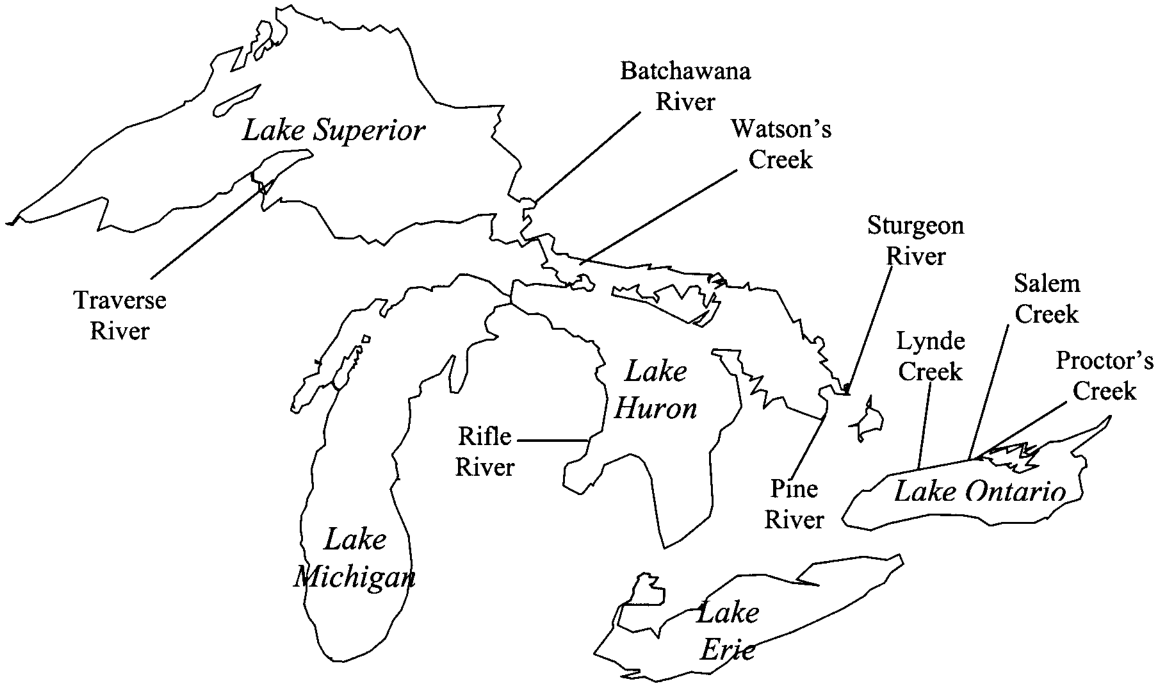

FIG. 1. Location of study streams in the Great Lakes basin.

To determine the effects of escapement on observed larval density and size composition, paired treatment and control plots of preferred larval habitat were identified and measured in the Traverse, Rifle, and Pine rivers. Slade *et al.* (2003) define preferred larval habitat as a combination of sand, fine organic matter, and detritus or aquatic vegetation. Plots were measured to the nearest 0.1 m in each dimension, stakes inserted at the corners, and the boundaries demarcated with string. Stream temperature (°C) and specific conductivity (µmhos), were measured in all plots. When possible, paired plots were selected so that they were contained within a contiguous area of habitat, with similar substrate composition, depth, and amount of visible debris and detritus. A minimum buffer of at least 1 m was left between each plot. One plot of each pair was randomly chosen

TABLE 1. Summary of physical and biological characteristics and numbers of larval lampreys captured in the streams used in the electrofishing effectiveness studies. Stream data from Fisheries and Oceans Canada and U.S. Fish and Wildlife Service.

Stream	Date of Study) (mm-yy)	Conductivity (µmhos)	Number of Larval Age Classes	Plot Size (m^2)	Number of Plots	Total Larval Lamprey Catch Electrofishing	Residual[a]	Control Plots
Rifle R.	09–96	440	3	5	20	314	338	538
Pine R.	08–96	440	3	5	5	110	84	91
Traverse R.	06-97	60	2	3	13	222	273	1007
Batchawana R.	07-98	50	3	5	19	920	482	—
Watson's Cr.	05-98	85	2	5	6	294	255	—
Sturgeon R.	06-98	285	2	5	20	134	50	—
Lynde Cr.	06-98	525	3	5	17	78	38	—
Salem Cr.	08-98	450	3	5	15	408	761	—
Proctor's Cr.	08-98	455	3	5	16	146	74	—

[a] Dredge or TFM capture, unmarked larvae only

as the plot to be electrofished, the other served as the control plot.

Sample plots were electrofished following the standardized methods and electrofishing gear settings used for quantitative sampling: a single-pass at the rate of 1.5 minutes/m^2, 125V, 3 pulses-per-second (pps) slow, 30 pps fast, and 25% duty cycle (Slade *et al.* 2003) by personnel experienced in electrofishing for larval lampreys. As many lampreys as possible, including indigenous species if present, were collected from the measured sample site during the allotted time and preserved in a 10% formalin solution. Larvae were subsequently identified to genus and measured for total length (± 1 mm).

Two methods were used to assess the number of lamprey larvae remaining within the electrofished plots and the total number of larvae in the control plots. A lampricide treatment was used to assess the number of lamprey larvae in plots on the Pine River. Sample plots in the Pine River were electrofished in August 1996, immediately prior to a scheduled lampricide treatment. After electrofishing, both electrofished and control plots were enclosed in 7-thread-per-cm screening, capable of confining all but young-of-the-year larvae, assuming that all remaining larvae would emerge from the substrate and remain within the enclosures for the duration of the lampricide treatment. After the lampricide treatment had passed through the screened-in enclosures the emergent larvae were collected and preserved in 10% formalin for later identification to genus and measurement (± 1 mm total length).

Dredging was used to determine the number of larvae in the plots in the Traverse and Rifle rivers. Immediately after electrofishing was completed in the Traverse and Rifle rivers, the substrate in the electrofished and control plots was evacuated to a depth of 12 cm using a modified suction dredge (Bergstedt and Genovese 1994). Water was pumped through a tapered orifice creating a high velocity jet stream within a flow-eduction tube. This produced a strong vacuum within a flexible intake pipe, allowing sites to be evacuated without passing the materials through the pump. Substrate, detritus, and larvae were transported through the intake pipe and filtered through a screening device with a 1 mm aperture. This collection of sediment and debris was examined, and the larvae removed and preserved in 10% formalin for later identification and measurement.

Overall Electrofishing Efficiency

Electrofishing efficiency in each plot was estimated as the ratio of X/Y, where X is the total electrofishing catch in the treatment plots and Y is the sum of the electrofishing and dredge catch in the treatment plots (Rifle and Traverse rivers) or electrofishing catch and lampricide treatment catch (Pine River). This estimate of electrofishing efficiency is made with the assumption that both the dredge technique and the TFM treatment would capture all larvae remaining in the plots after electrofishing was completed. For each stream, a mean efficiency and variance was calculated from the pooled plot data, and a single, overall mean electrofishing efficiency was calculated by pooling the three stream estimates, each weighted by the inverse of its variance (Hilborn and Walters 1992).

Escapement

To determine the effect of escapement on estimates of electrofishing efficiency, the log-transformed densities of sea lamprey larvae from treatment plots were compared to those from control plots using paired t-tests (Zar 1984). A significantly lower density in the electrofished plots may indicate that a substantial proportion of lamprey had left the plot area, possibly due to electrofishing effects. Paired t-tests were used to examine the difference in log-transformed density of larvae greater than 89 mm between the treatment and control plots. Larvae that are above the 89 mm threshold are expected to be large enough to potentially metamorphose the year following capture, thus accurate estimates of abundance of these larvae are especially important for stream ranking procedures.

Size Selectivity

A two-sample Kolmogorov-Smirnov test (Sokal and Rohlf 1995) was used to compare the length-frequency distributions of sea lamprey larvae size-classes (< 55 mm, 56 to 105 mm, > 105 mm) captured by electrofishing to those captured in control plots. A significant difference in frequency distribution between electrofishing catch and control plot catch would suggest that electrofishing samples do not represent the size structure of the true larval population.

Second Study

In 1998, an additional six streams (Salem, Proctor's, Lynde, and Watson's creeks, and the Sturgeon and Batchawana rivers, Fig. 1) were selected for a second study, again with the criteria of larval densities > 5 per m^2 and the presence of multiple year classes. An additional selection criteria was that these streams represented the range of water conductivity found in streams throughout the Great Lakes (Table 1).

The dredge sampling procedure was enhanced to examine the effects of size selectivity using the dredge technique on the estimate of initial plot abundance. An assumption in the initial study was that the dredge was 100% effective at capturing lamprey larvae. To test this assumption and measure the overall effectiveness of the dredge technique, a Peterson mark-recapture procedure (Robson and Regier 1964) was incorporated into the study design. The mark-recapture procedure also provided a supplemental method for estimating initial plot abundance.

To examine the effects of environmental variables on electrofishing sampling efficiency, unpaired plots of preferred habitat were measured, staked, and electrofished as described in the initial study. To reduce variability due to operator experience, the same person electrofished each sample plot. Immediately after electrofishing, the plots were enclosed in 7-thread-per-cm screening. The screening was anchored at the bottom in continuous contact with the substrate and extended vertically to a minimum of 10 cm above the surface of the water. Electrofished larvae collected from each plot were anesthetized, measured to total length, tail-clipped, returned to the enclosure, and visually monitored to ensure each successfully burrowed into the substrate within the enclosure. A suction dredge was used to evacuate the habitat to a depth of 12 cm. All larvae collected from dredging activities were preserved in 10% formalin for later identification, examination for marks, and measurement (± 1 mm).

If catchability using the dredge technique varies with larval length, using a Petersen estimate to calculate initial abundance of lamprey larvae in the plot would underestimate the plot population size (Anderson 1995, Bohlin and Sundstrom 1977). There is evidence that catchability of lamprey larvae using the dredge technique varies with lamprey size, with small lamprey being less vulnerable to capture. To compensate for this unequal catchability, the larval catches were divided into 5 length bins (0 to 80 mm, 81 to 100 mm, 101 to 120 mm, 121 to 140 mm, and >140 mm). Modified Petersen estimates (Seber 1982) were calculated for each length bin, as:

$$\hat{N}_i = \frac{(M_i + 1) * (C_{Di} + 1)}{(R_i + 1)} - 1 \qquad (1)$$

where: $\hat{N}_i$ = abundance of larvae in length bin i
M_i = the number of marked lampreys in length bin i that were released, corresponding to electrofishing catch for the length bin
C_{Di} = the number of lampreys in length bin i examined for marks, corresponding to the dredge catch
R_i = the number of marked larvae in C_{Di}

The proportion of larval lampreys captured in each bin was estimated as:

$$\hat{p}_i = \frac{M_i}{\hat{N}_i} \qquad (2)$$

where: M_i = electrofishing catch in length bin i
$\hat{N}_i$ = the estimated abundance in bin i for each plot, i = 1–5

The variance of the dependent variable, $\hat{p}_i$, is not homogeneous for these data. The variance of $\hat{N}_i$ is inversely related to the number of lampreys recaptured, R_i, in the second sampling period of a mark-recapture estimate (Krebs 1999). The number of lampreys recaptured will vary among length increments within a plot, as well as among plots within and among rivers, resulting in non-homogeneous variance in $\hat{N}_i$ and subsequently $\hat{p}_i$. The variance of the capture proportion was estimated following Steeves (2002) as:

$$\mathrm{var}(\hat{p}_i) = \frac{M_i^2 \cdot \dfrac{R}{(R_i + 1)^2}}{(\hat{N}_i)^2} \qquad (3)$$

where R = the total number of recaptures from the plot, and other variables as previously defined.

Effects of Environmental Variables

A quasi-likelihood function is typically used to estimate parameters for non-linear models with response data that take the form of proportions (Bayley 1993). In the case of this model of electrofishing efficiency, the quasi-likelihood function behaves in a manner similar to a log-likelihood function that is based on an underlying binomial distribution (Collett 1991). A weighted general linear model (GLM) with a logit link function in S-Plus (Mathsoft 2000) was used to estimate the parameters of the model for electrofishing efficiency, with capture proportion specified as the response variable. Since the overall abundance for each length bin, $\hat{N}_i$, in the calculation of capture proportion is estimated rather than known, its use as the binomial denominator in the model is not appropriate. The value for the binomial denominator was set equal to one (Collett 1991, p. 278), and the formula within the GLM was specified as:

$$\sim\text{Weights}^*(\text{Capture Proportion} - \text{Model}), \quad (4)$$

where the algorithm minimizes the sum of the squared differences between the left- and right-hand sides, treating the empty left-hand side as zero (Venables and Ripley 1999, p. 244). The weights are the inverse of the variance of the capture proportion described in the previous section.

The weighted logistic equation was used to model the relationship between the proportion of larval lampreys captured by electrofishing and larval length (X_1), log(density) (X_2), water temperature (X_3), conductivity (X_4), and depth (X_5):

$$\hat{p}_i = \frac{1}{(1+\exp(-(\hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \hat{\beta}_3 X_3 + \hat{\beta}_4 X_4 + \hat{\beta}_5 X_5 + \text{interaction terms})))} \quad (5)$$

Instead of simply using the mid-point of the length range for each length bin, the effect of the independent variable larval length (X_1) was calculated as the mean length of the larvae caught by electrofishing in each length bin for each individual plot. The mark-recapture estimate of initial plot abundance divided by the measured plot area was used as an estimate of plot density. Initial plot abundance was estimated as the sum of the individual length bin estimates, $\hat{N}_i$, in each plot. Larval density per square metre was calculated as a function of all lampreys present within the plot, regardless of species. The sampling protocol (Slade *et al.* 2003) instructs field crews to collect as many lampreys as possible from the measured plots within the allotted time. Although non-target lampreys are not included in calculations of growth and metamorphosis, their presence affects the surveyors' sampling effectiveness. Log(density) was used as the independent variable (X_2) since the distribution of the density calculations in the data was skewed (Kay and Little 1987).

Model fitting procedures followed those outlined in Neter *et al.* (1996), Collett (1991), and Hosmer and Lemeshow (1989). The variables identified as significant using Wald's Chi-square test were examined for appropriate scale in the logit and for interaction terms that were both statistically significant and biologically meaningful. Outliers were identified using Pearson residuals, analogous to Studentized residuals in least-squares regression (Hosmer and Lemeshow 1989). The final model of electrofishing effectiveness was selected using a likelihood-ratio goodness-of-fit test.

Data analyses were done using the S-Plus (MathSoft 2000) and Systat (Wilkinson 1999) software packages.

RESULTS

Overall Electrofishing Efficiency

Electrofishing efficiency was remarkably similar between the Rifle, Pine, and Traverse rivers (Fig. 2). There was no significant difference in efficiency (ANOVA, p = 0.37) between the three streams. The estimate of electrofishing efficiency, weighted by the inverse of the variance of mean efficiency for each stream, was 0.482, or 48.2% (95% C.I. 0.337–0.627). This fixed efficiency estimate was adopted into the Empiric Stream Ranking System and is currently used to adjust the observed catch of

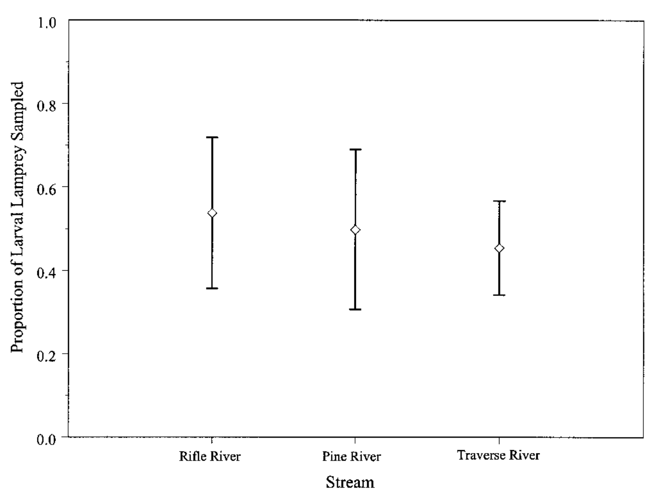

FIG. 2. Proportion of larval lamprey sampled in the initial study in the Rifle, Pine, and Traverse Rivers. The open diamonds represent the mean sampling proportion. The error bars are ± 1 standard deviation of the mean.

TABLE 2. A comparison of the log-transformed densities of lamprey larvae from treatment and control plots in the Rifle, Pine, and Traverse Rivers.

			All Larvae			Larvae > 89 mm		
River	Number of Plots	Plot Type	N	log(Mean Density) [s.e.]	P-value	N	log(Mean Density) [s.e.]	P-value
Rifle	20	Treatment	652	1.56 [0.178]	0.049	167	0.264 [0.251]	0.03
		Control	538	1.18 [0.247]		108	–0.190 [0.263]	
Pine	5	Treatment	194	1.84 [0.354]	0.069	91	1.137 [0.338]	0.12
		Control	91	0.663 [0.553]		39	–0.032 [0.744]	
Traverse	13	Treatment	495	2.43 [0.137]	< 0.001	21	0.009 [0.463]	0.70
		Control	1,007	3.18 [0.108]		20	–0.203 [0.117]	

lamprey in tributaries to the Great Lakes (Christie *et al.* 2003, Slade *et al.* 2003).

Escapement

The examination of the effects of escapement on calculated larval density yielded mixed results (Table 2). Significantly more ($P < 0.05$) larvae of all sizes were found in treatment plots in the Rifle River (Table 3a). Larvae also tended to be more abundant in the treatment plots of the Pine River, although not significantly so. Larvae 89 mm and smaller were more abundant ($P < 0.001$) in the control plots of the Traverse River, while densities of larvae greater than 89 mm in length were similar in both treatment and control plots. Prior to beginning the study it was expected that control and treatment plot densities would either be equal, indicating no escapement due to electrofishing activities, or that control plots would have higher densities than electrofishing plots, an indication of larval escapement. Given the higher densities of larvae in the electrofishing plots in two of the three rivers, the initial assumptions were not supported in this study.

Size Selectivity

The Kolmogorov-Smirnov test indicated a significant difference ($P < 0.001$) between the cumulative distribution functions for the lengths of lamprey larvae collected from the control and treatment plots in the Rifle River (Table 3a). The cumulative distribution of larval lamprey length in the treatment and control plot larvae from the Pine and Traverse rivers were not significantly different ($P > 0.10$). Subsequent analyses of the individual size classes (< 55mm, 55 to 105 mm, > 105 mm) within the Rifle River indicated that this difference was solely attributable to differences between the treatment and control plot cumulative distributions for the 55 to 105 mm size class of larvae (Table 3b).

Effects of Environmental Variables

Between 6 and 20 plots were sampled in each of the 6 streams in the second study (Table 1). Recapture of all of the marked lampreys occurred in 4 of the 93 total plots sampled, indicating that the dredge technique does not consistently census all lampreys within a sample plot. Examination of the length distribution of the recaptured larvae also indicated that larger larvae were more likely to be recaptured using the dredge technique. The length bin procedure (Sullivan 1956) was used to provide more accurate estimates of larval lamprey abundance, that were subsequently used to estimate the proportion of lamprey captured by electrofishing.

A scatterplot of the logit of capture proportion, $\log(\hat{p}_i/1 - \hat{p}_i)$ shows that capture proportion significantly ($P < 0.0001$) increases as the length of larvae increases (Fig. 3). Scatterplots of the logit of capture proportion for each length bin versus the site-specific variables show a significant ($P < 0.0001$) decrease in capture proportion as larval lamprey density and water conductivity increase (Fig. 4). Water temperature and plot depth do not appear to affect the capture proportion of lamprey larvae.

Individually fitting each explanatory variable to a logistic model of capture proportion indicated that each variable significantly reduces the model deviance. Based on these univariate results, all variables were included in the initial multivariate model. In the multivariate model the effect of temperature, after adjusting for all other terms in the

TABLE 3A. Results of paired Kolmogorov-Smirnov test on lengths of larvae captured in treatment (electrofishing + dredge/lampricide) and control (dredge or lampricide) plots in the initial study.

Stream	Plot Type	N	Length (mm) Mean	Median	Mode	Min	Max	P-value
Pine	Treatment	194	80.89	79	45	34	144	p > .10
	Control	91	79.92	72	multiple	39	144	
Rifle	Treatment	652	72.48	78	82	23	159	p < .001
	Control	538	66.17	69.5	36	24	158	
Traverse	Treatment	495	39.78	30	23	16	148	p > .10
	Control	1,008	38.06	31	25	14	155	

TABLE 3B. Results of paired Kolmogorov-Smirnov test on the individual length-classes of larval lamprey captured in treatment (electrofishing + dredge) and control (dredge) plots within the Rifle River.

Length Class	Plot Type	N	Length (mm) Mean	Median	Mode	Min	Max	P-value
< 55 mm	Treatment	209	34.26	34	36	23	54	p > .10
	Control	212	34.41	34	36	24	49	
55–105 mm	Treatment	354	82.15	82	82	60	104	p < .001
	Control	273	79.58	79	71	55	104	
> 105 mm	Treatment	89	123.8	123	108	107	159	p > .10
	Control	53	124.1	124	117	106	158	

model, was not significant (P = 0.38). As well, the intercept term does not significantly (P = 0.086) improve the model fit, and was removed from the model.

After determining the significant main effects, each of six potential interaction terms was sequentially fit to the model. Three of the individual interaction terms significantly improved the fit of the model, and all three terms included with the main effects significantly reduced the model deviance (P < 0.001). The logistic model of electrofisher sampling proportion therefore included the four main effects as well as the three interaction terms (Table 4). Although the parameter estimate for conductivity was no longer significant, it was retained in the model due to its interaction with other variables.

DISCUSSION

The fact that the dredge technique does not census a sample plot limits the conclusions that can be drawn from the results of the initial study. If all remaining lampreys were not collected from the treatment plots, the sum of electrofishing and dredge catches would underestimate the true initial density, resulting in an overestimation of overall electrofishing efficiency. In examining the effects of escapement on observed electrofishing catch, it is not certain whether the lamprey in the treatment plots escape capture due to electrofishing effects or are missed in the subsequent dredging. Since some lamprey escape dredge capture the length distribution observed in either the treatment or control plots may not reflect the entire length range of lamprey larvae that were present. Further investigation into the effects of escapement and the potential for size selectivity using backpack electrofishing gear is needed, perhaps within a more controlled setting using sample plots containing a known number lamprey larvae of a known length distribution.

Environmental effects have variable influence on collecting effectiveness using electrofishing gear, depending upon the sampling strategy (Bohlin *et al.* 1989), type of gear (Bergstedt and Genovese 1994, Weddle and Kessler 1993), and species sought (Fievet *et al.* 1999, Pusey *et al.* 1998, Strange *et al.* 1989). For larval lamprey sampled with backpack electrofishing gear in tributaries to the Great Lakes, collecting effectiveness significantly declined as

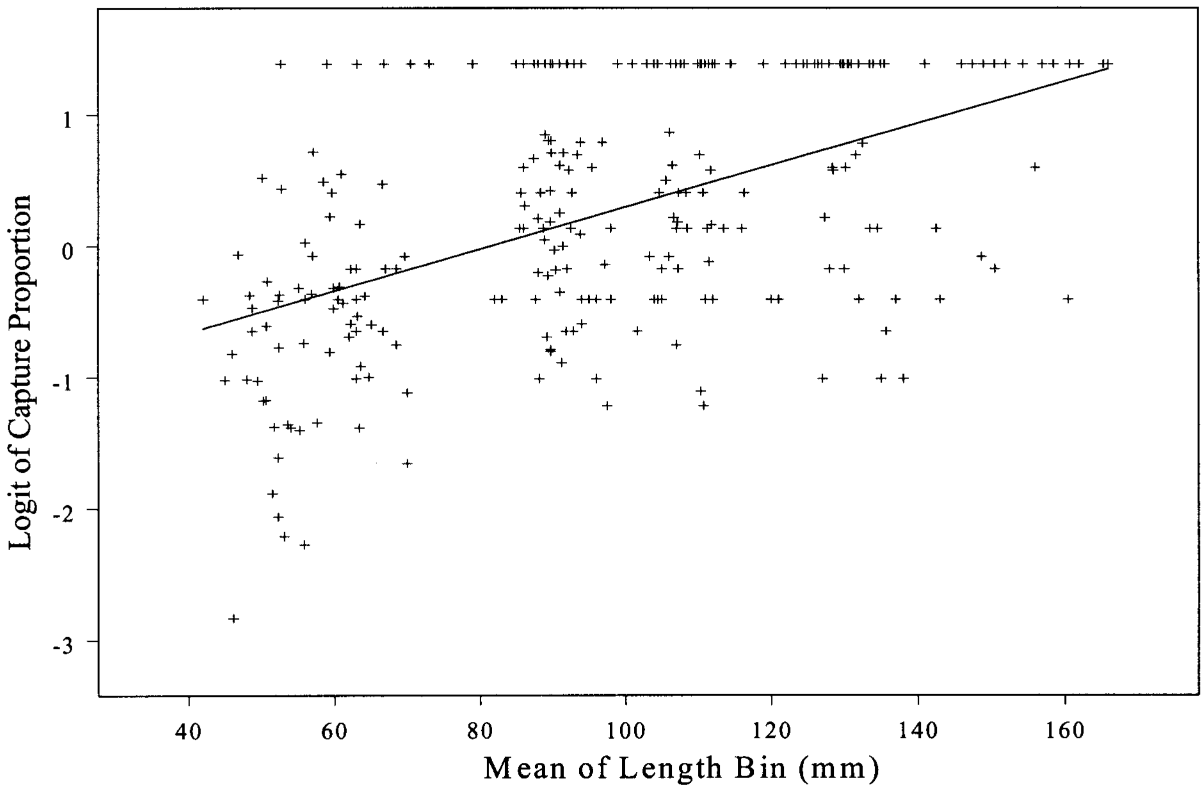

FIG. 3. The logit of the capture proportion log ($\hat{p}_i/1 - \hat{p}_i$) versus the mean length of lamprey larvae within 5 length bins: 0 to 80 mm, 81 to 100 mm, 101 to 120 mm, 121 to 140 mm, and > 140 mm.

water depth and larval density increased, but significantly increased as length of lamprey increased. This is consistent with other reported effects of environmental variables on the effectiveness of backpack electrofishing (Hill and Willis 1994, Hardin and Connor 1992, Bohlin *et al.* 1989, Zalewski 1985). Although temperature is known to affect both conductivity (Weisser 1994, Bohlin *et al.* 1989) and larval response to electrical stimulus (Hintz 1993), the temperature range in this study (10 to 22°C) did not appear to influence the physical response of lamprey larvae, and so did not influence sampling effectiveness.

The variables selected for investigation in this study are readily measured using equipment that is easily portable for field use. Although some of the environmental variables significantly reduced the deviance of the logistic model, there are other factors that influence electrofishing effectiveness. Perhaps the most important of these is the experience of the personnel operating the electrofishing gear (Hardin and Connor 1992). For example, the density at which an operator becomes limited in the ability to capture larval lampreys during the first pass of electrofishing will vary depending upon physical ability and electrofishing experience (Hardin and Connor 1992). Density estimates from samples collected by experienced operators may be systematically higher than those made by less experienced personnel, resulting in biased population estimates. One solution to this problem would be to assess the sampling efficiency of each individual under a variety of sampling conditions, creating an efficiency model for each field person. However, the time required to replicate this study for all operators makes this an impractical solution. Perhaps the best solution to reduce the potential bias in population estimates is to ensure that each stream is assessed by multiple operators representing a range of electrofishing experience. Although this would increase the variability in the sampled data, it would also reduce the potential sampling bias of individual operators in selecting sample plots. This would result in more comparable estimates of mean stream density and larval lamprey abundance.

Variability in sampling effectiveness for teleosts

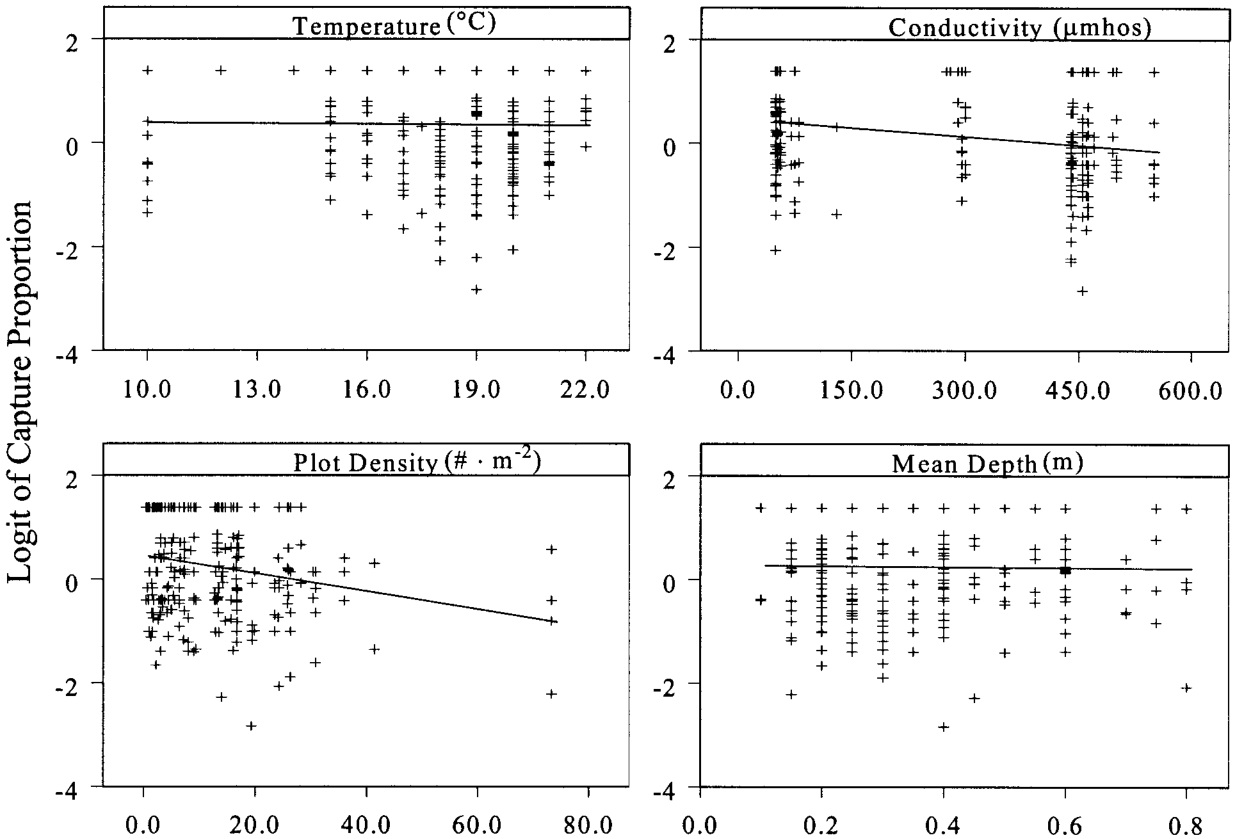

FIG. 4. Scatterplots of the logit of capture proportion, log ($\hat{p}_i/1 - \hat{p}_i$), of initial plot abundance versus temperature, conductivity, plot density, and mean depth. The line in each chart is the best linear fit for the data.

is also affected by variability in the power output of the electrofishing device (Beaumont *et al.* 2000, Burkhardt and Gutreuter 1995). Standardizing power output by adjusting the voltage output of the electrofishing gear depending upon water conductivity and temperature optimizes the transfer of power from water to fish, producing a less variable capture proportion. However, larval lamprey emergence from the substrate depends upon applying a level of stimulus sufficient to initiate emergence without inducing galvanonarcosis in the burrowed lamprey. Thus, emergence of a larval lamprey is a function of power transfer from substrate to larvae, and this varies with substrate composition (Bohlin

TABLE 4. Final parameter estimates for the logistic model of electrofishing efficiency in the six streams examined in the second study, 1998.

Variable	β	S.E. (β)	Wald $\chi 2$	P-value
Mean Length	0.0225	1.77×10^{-3}	161.04	< 0.0001
log(Density)	–0.3322	4.16×10^{-2}	63.68	< 0.0001
Conductivity	0.00043	4.03×10^{-4}	1.12	0.289
Mean Depth	–0.8843	1.79×10^{-1}	24.40	< 0.0001
Mean Length × Conductivity	–0.000013	5.29×10^{-6}	6.15	0.013
log(Density) × Conductivity	–0.000133	5.54×10^{-5}	5.76	0.016
Mean Depth × Conductivity	–0.0068	9.54×10^{-4}	50.27	< 0.0001

Residual Deviance: 579.8 on 253 df

et al. 1989) and the orientation of the larvae within the electrical field (Hintz 1993, Weisser 1994). Since the specific conductance of substrate is usually higher than that of the surrounding water (Bohlin *et al.* 1989) and there is a high degree of variability in the composition of substrate used by larval lampreys (Beamish and Lowartz 1996, Potter *et al.* 1986), standardizing the power output based on parameters of the water column may not reduce variability in the observed catch of lamprey larvae. The effects of standardizing power on sampling effectiveness for larval lampreys should be investigated in any additional studies.

The logistic regression incorporates the effects of the sampling conditions and lamprey density into a prediction of collecting effectiveness given the size of the lamprey. The effects of larval lamprey size and site-specific variables on estimates of larval and parasitic lamprey abundance can be illustrated by comparing abundance estimates derived from the logistic estimate of electrofishing efficiency with estimates derived from the current electrofishing efficiency estimate of 48.2% used in the Empiric Stream Ranking System (Christie *et al.* 2003). As an example, assume that two different streams are sampled and the same number and size structure of lamprey are obtained in each collection (Fig. 5). The two streams represent, respectively, the logistically optimal sampling conditions of low water depth, larval density, and stream conductivity (stream A) and the worst sampling conditions, where all sampling attributes have high values (stream B). Since the number and size structure of the larval lamprey collection is the same for each stream, the fixed efficiency of 48% would estimate the total larval population and the potential number of parasitic individuals to be the same. If the cost of treatment is comparable for both streams, it is equally cost-effective to treat either. However, incorporating the effects of environmental variables into the population estimate yields different population estimates between the two streams. Since electrofishing effectiveness is lower when sampling larvae under the extreme sampling conditions of stream B, the observed catch represents a much lower proportion of the true population. Consequently, the population estimate of larvae and the potential production of parasitic individuals will be larger than that of stream A. If the cost of treating either stream is still the same, it becomes more beneficial to treat stream B, as more potential parasitic lamprey will be removed for each dollar spent. For this reason, it is recommended that Sea Lamprey

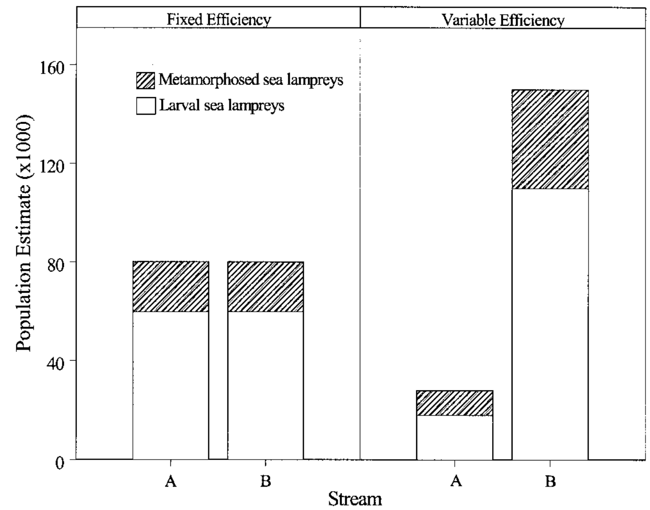

FIG. 5. A hypothetical comparison of fixed (0.48) versus logistic model estimates of sea lamprey populations. Stream A represents optimal sampling conditions: Conductivity = 50 µmhos, Density = 0.5 larvae per m², Mean Depth = 0.1 m; stream B represents poor sampling conditions: Conductivity = 550 µmhos, Density = 20.0 larvae per m², Mean Depth = 0.8 m.

Control managers incorporate the logistic estimate of electrofishing efficiency into the model used to prioritize streams for lampricide treatment, to more accurately reflect the effects of environmental variables on electrofishing efficiency.

Estimates of potential larval lamprey habitat range from 500 to 800,000 square metres in tributaries to the Great Lakes. From a management perspective, an estimated difference of 0.1 larvae per m^2 can substantially impact both the overall population estimate and estimate of potential parasitic production. Since streams are prioritized for treatment based on the cost of eliminating the potential parasitic population, a change in estimated density of 0.1 larvae per m^2 could make the difference between lampricide treatment the following year or deferral to a later date, allowing parasitic lamprey to escape to the lake population. A better understanding of how environmental variables influence the effectiveness of sampling lamprey larvae using backpack electrofishing gear will enable the control agents to more accurately estimate the potential parasitic population of a stream. This will result in a more cost-efficient application of treatment efforts to control sea lamprey in the Great Lakes.

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